

Rebhan, David; Dittrich, Paul-Gerald; Rosenberger, Maik; Notni, Gunther:

Radiometric extension of a measurement arrangement in accordance with the EMVA 1288 standard for camera characterization in UV to NIR wavelength range

<i>Original published in:</i>	Journal of physics. Conference Series / Institute of Physics - Bristol : IOP Publ.. - 1379 (2019), art. 012056, 6 pp.
<i>Original published:</i>	2019-11-01
<i>ISSN:</i>	1742-6596
<i>DOI:</i>	10.1088/1742-6596/1379/1/012056
<i>[Visited:</i>	2020-06-09]



This work is licensed under a [Creative Commons Attribution 3.0 Unported](https://creativecommons.org/licenses/by/3.0/) license. To view a copy of this license, visit <https://creativecommons.org/licenses/by/3.0/>

Radiometric extension of a measurement arrangement in accordance with the EMVA 1288 standard for camera characterization in UV to NIR wavelength range

David Rebhan¹, Paul-Gerald Dittrich^{1,2*}, Maik Rosenberger¹, Gunther Notni¹

¹ Technische Universität Ilmenau,
Faculty of Mechanical Engineering,
Group for Quality Assurance and Industrial Image Processing,
Gustav-Kirchhoff-Platz 2, 98693 Ilmenau, Germany
² SpectroNet c/o Technologie- und Innovationspark Jena GmbH,
Hans-Knöll-Straße 6, 07745 Jena, Germany

E-mail: paul-gerald.dittrich@tu-ilmenau.de

Abstract. For the objective comparison of different cameras or image sensors, it is necessary to describe their image acquisition channel by suitable parameters. The EMVA 1288 standard, developed by camera manufacturers and research institutes, distinguishes itself from other standards by considering the camera as a linear model. The camera is treated as a black box of which only pixel size and exposure time must be known. The recording of standardized test images is also omitted, allowing the camera to be described without optics. The only input variable of the linear camera model of the EMVA 1288 standard is the number of photons that hit a pixel of the image sensor during the exposure time. Therefore, the correct determination of the photon count is essential to calculate important camera parameters from the linear camera model, such as quantum efficiency or signal-to-noise ratio. To determine the number of photons, the irradiance of the radiation incident on the image sensor must be measured. This is usually done using a radiometer instead of the camera or image sensor. The number of photons per pixel during the exposure time can then be calculated from the irradiance, considering constants like the wavelength of the incident radiation, the area of the pixel and the exposure time of the camera. Calibrated radiometers were procured which are sensitive in the UV-A, VISNIR and NIR wavelength ranges in order to be able to perform camera or image sensor characterizations according to the EMVA 1288 standard in these wavelength ranges in the future.

1. Introduction

The EMVA 1288 standard was published in 2005. The reason for the publication of this standard by the European Machine Vision Association (EMVA) was, among others, the difficult comparability of the data sheets of the camera manufacturers. Often different camera parameters or different units were used. This made it difficult to select the right camera for a particular application. The EMVA 1288 standard defines an accurate and reliable measurement procedure and guidelines for the presentation of the measurement results. This standard makes it much easier to compare cameras and image sensors from

* To whom any correspondence should be addressed.



different manufacturers. The EMVA 1288 standard was developed by a consortium of companies and research institutes in Europe [1]. The current version of the standard is 3.1. The calculations of the EMVA 1288 standard are based on a linear camera model (figure 1) [2].

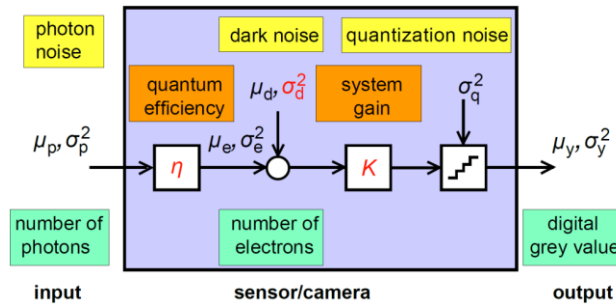


Figure 1. Schematic representation of the linear camera model of the EMVA 1288 standard [2]. During the exposure time an average number of photons μ_p hits on the surface of a pixel. The input value μ_p is converted into the output value of the digital grey value μ_y in the camera model.

The linear camera model contains only three parameters, the quantum efficiency η , the dark noise σ_d and the camera gain K . When photons hit the pixel, only a certain part of them is absorbed and generates charge carriers μ_e . The proportion of generated charge carriers μ_e to incident photons μ_p is referred to as quantum efficiency η (1).

$$\eta(\lambda) = \frac{\mu_e}{\mu_p} \quad (1)$$

The quantum efficiency η refers to the entire area of a pixel, not only to the photosensitive part. The quantum efficiency is dependent of the wavelength λ of the incident light [2]. The average number of photons μ_p that hit one pixel of the surface A during the exposure time t_{exp} can be calculated using the irradiance E on the sensor surface (2).

$$\mu_p = \frac{AEt_{exp}}{hc_0/\lambda} \quad (2)$$

Using Planck's constant $h = 6,6260755 \cdot 10^{-34} [Js]$ and the speed of light $c_0 = 2,99792458 \cdot 10^8 [m/s]$, the average number of photons μ_p can be simplified calculated (3).

$$\mu_p [photons] = 50,34 \cdot A [\mu m^2] \cdot t_{exp} [ms] \cdot \lambda [\mu m] \cdot E \left[\frac{\mu W}{cm^2} \right] \quad (3)$$

The digital gray value μ_y results from the sum of the photon-induced charge carriers μ_e and the dark signal μ_d integrated over the exposure time t_{exp} , multiplied by the absolute gain factor K (4).

$$\mu_y = K(\mu_d + \mu_e) = \mu_{y.dark} + K\mu_e \quad (4)$$

The absolute gain factor K has the dimensionless unit number of electrons per digital value $[e^-/DN]$. However, the relationship between equation (1) and (4) cannot be determined directly, since the number of charge carriers μ_e is unknown. Only the relationship between the photon number per pixel μ_p and the image signal μ_y can be determined by inserting equation (1) into equation (4) [2] (5).

$$\mu_y = \mu_{y.dark} + K\eta(\lambda)\mu_p \quad (5)$$

This is the linear camera characteristic whose axis section forms the dark signal $\mu_{y.dark}$ and whose gradient is the product of the absolute amplification factor K and the quantum efficiency η . The gradient of the camera curve is also referred to as sensitivity R . However, the unknown camera parameters K , η and σ_d , marked red in figure 1, can only be determined unambiguously from the camera characteristic

after an analysis of the noise. The accumulated electrons are assumed to be Poisson distributed thus their variance is equal to the mean value (6).

$$\sigma_e^2 = \mu_e \quad (6)$$

The same applies to the variance of the photon noise σ_p^2 . Due to the linear camera characteristic, all noise sources resulting from the transport or amplification of the charge carriers can be combined into a single noise source, the dark noise σ_d^2 [2]. Another noise source that must be included in the consideration is the so-called quantization noise, due to the final analog-digital conversion. Their variance can be described as follows: $\sigma_q^2 = 1/12 DN^2$ [2]. Thus, including equations (4) and (5), total noise σ_y^2 is obtained (7).

$$\sigma_y^2 = K^2 \sigma_d^2 + \sigma_q^2 + K(\mu_y - \mu_{y.dark}) \quad (7)$$

With known K , the quantum efficiency η can be calculated from the gradient of the camera curve R from equation (8). This method is called photon transfer method (figure 2) [2].

$$\eta = \frac{R}{K} \quad (8)$$

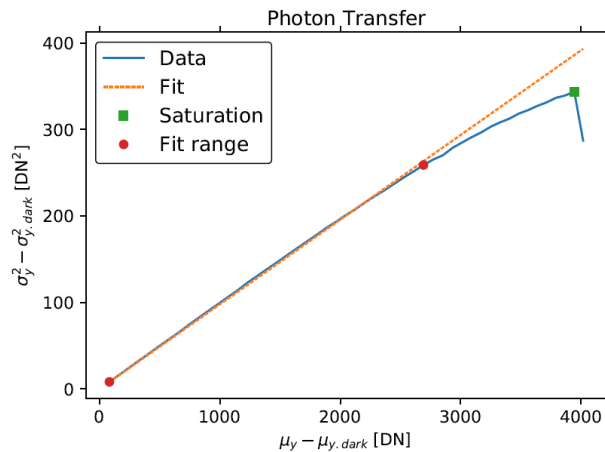


Figure 2. Exemplary photon transfer curve [2]. The absolute gain factor K can be read directly from the slope of the photon transfer curve. The variance of the dark noise σ_d^2 results from the axial section of the photon transfer curve after deduction of the quantization noise.

2. Adding radiometer to the EMVA 1288 test system

In accordance to the manufacturer Gigahertz Optik, the radiometers to be connected are pn photodiodes. However, the radiometers differ in the semiconductor materials of their photodiodes. For example, GaP (Gallium Phosphide) is used as the semiconductor material for the UV radiometer. In the NIR radiometer the photodiode is based on the semiconductor material InGaAs (Indium Gallium Arsenide), the VISNIR radiometer is based on conventional Si (Silicon) (figure 3).



Figure 3. UV, VISNIR and NIR radiometers by Gigahertz-Optik. Each radiometer is equipped with a diffuser in order to minimize the directional dependence of the irradiance by generating a diffuse transmission [3].

All radiometers have the same geometric proportions, which simplifies mechanical coupling to the EMVA 1288 test system. By combining color glass filters with the optimized diffuser, the sensitivity curve of each sensor is approximated to a rectangle function of the respective spectral range (figure 4) [4].

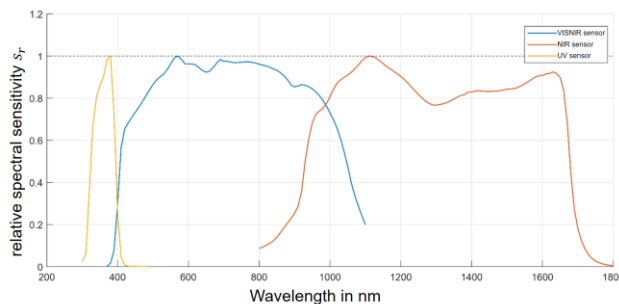


Figure 4. Relative spectral sensitivity of the three radiometers. The adaptation of the relative spectral sensitivity to a rectangular function of the VISNIR and NIR measuring heads is clearly visible.

The measuring heads were set by the manufacturer to the integral irradiance of the respective rectangle function calibrated. This calibration factor is already set in the so called optometer module for each radiometer. However, this integral calibration factor cannot be used for (nearly) monochromatic measurements, because for a monochromatic measurement at least one irradiance value or calibration factor on the relative spectral sensitivity function must be available. In the following, this irradiance value is also referred to as the grid point. Therefore, the correct calibration factors for monochromatic measurements were determined on the basis of further calibration data from the manufacturer.

3. Example procedure for absolute calibration of radiometer for VISNIR

The relative spectral sensitivity s_r of the VISNIR radiometer was determined by the manufacturer by comparison with a reference standard BN-9102-118 IET 1008, whose spectral sensitivity is attributed to the national standards of the Physikalisch-Technische Bundesanstalt (PTB).

Irradiation was performed with the radiation of a halogen incandescent lamp [4] diffracted by a grating double monochromator. The relative spectral response can be shown (figure 5).

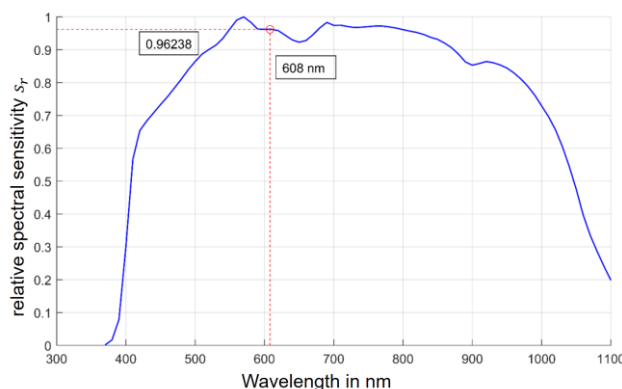


Figure 5. Grid point and relative spectral sensitivity of VISNIR radiometer. In addition to the relative spectral sensitivity function, the manufacturer measured a grid point. The irradiance was determined by a 1000 W lamp with a 608 nm filter IET 1899, FWHM 11 nm and a reference receiver whose spectral irradiance is attributed to the national standards of the PTB [5].

The manufacturer has determined relative measurement uncertainty of the relative spectral sensitivity measurement (table 1).

Table 1. Relative uncertainty of measurement of the relative spectral sensitivity calibration of the VISNIR radiometer [4].

Wavelength range in nm	Uncertainty of measurement in %
380 – 900	± 4
910 – 1070	$\pm 4,5$
1080 – 1100	± 5

In order to determine the correct calibration factors k_λ , the relative spectral sensitivities specified by the manufacturer in 10 nm steps were first interpolated linearly in 1 nm steps. This results in a relative spectral sensitivity s_r 0.96238 at the 608 nm grid point (see figure 5). Since the relative spectral sensitivity values are normalized to 1, the sensitivity function is first adapted so that it assumes the value 1 at the grid point (9).

$$s_k(\lambda) = \frac{1}{s_r(608)} \cdot s_r(\lambda) = \frac{1}{0,96238} \cdot s_r(\lambda) \quad (9)$$

The calibration factor k at the grid point is known and results from the photocurrent I of the radiometer and the irradiance determined by the reference receiver E (10).

$$k_{608} \left[\frac{A}{W/m^2} \right] = \frac{I[A]}{E[W/m^2]} \quad (10)$$

Thus the irradiance E can be determined depending on the sensitivity $s_k(\lambda)$ (11).

$$E = \frac{I}{k_{608}} \cdot \frac{1}{s_k(\lambda)} \quad (11)$$

The constant k_{608} can be combined with the sensitivity $s_k(\lambda)$ to a calibration factor, here referred to as spectral irradiance sensitivity k_λ (12).

$$k_\lambda = \frac{k_{608}}{s_k(\lambda)} = \frac{k_{608}}{s_r(\lambda)} \quad (12)$$

The spectral irradiance sensitivity k_λ was calculated over the entire sensitivity range of the VISNIR radiometer in steps of 1 nm (figure 6).

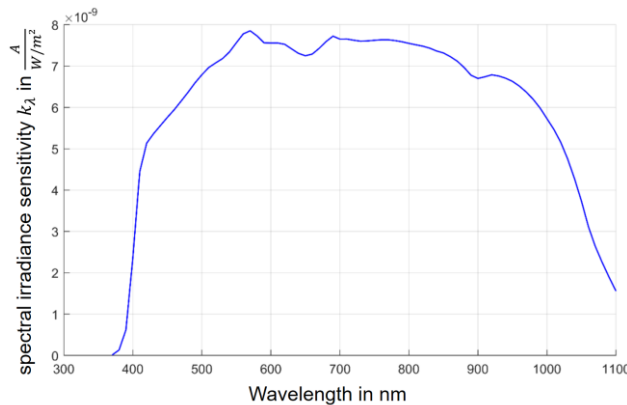


Figure 6. Determined spectral irradiance sensitivity of the VISNIR radiometer. The measurement program determines the spectral irradiance sensitivity k_λ from the given wavelength and divides the selected photocurrent I by k_λ . Thus the correct irradiance E is output for monochromatic measurements.

The course of k_λ reflects the course of the sensitivity function (see figure 6). The irradiance E can simplified be calculated (13).

$$E \left[\frac{W}{m^2} \right] = \frac{I[A]}{k_\lambda \left[\frac{A}{W/m^2} \right]} \quad (13)$$

By determining the absolute values of the spectral irradiance sensitivity over a measured sampling point, the relative measurement uncertainties of both measurements performed by the manufacturer add up. According to the manufacturer, the relative measurement uncertainty of the measurement of the sampling point is $\pm 5\%$ [5]. The relative measurement uncertainties of the relative spectral sensitivity

calibration depend on the observed wavelength and ranges between $\pm 4\%$ and $\pm 5\%$ (see table 1). The calibration of the UV and NIR radiometers was carried out analogously to the calibration of the VISNIR radiometer.

4. Results and summary

This paper deals with the radiometric extension of a measurement arrangement in accordance with the EMVA 1288 standard for camera and or image sensor characterization in UV, VISNIR and NIR wavelength ranges. The measurement of the irradiance is of great importance here, in order to calculate the number of photons that hit the image sensor during the exposure time. The irradiance was previously measured using a non-calibrated photodiode from Texas Instruments whose spectral sensitivity is limited to the VISNIR range. In order to extend the measurable radiation range, three radiometers of the company Gigahertz-Optik were added to the measurement arrangement.

In this paper, a method was developed with which the spectral irradiance sensitivity of each radiometer can be determined. The absolute sensitivity values were calculated based on the relative spectral calibration and a grid point.

In summary, it can be said that the new radiometric measuring system is now usable in our EMVA 1288 measurement arrangement for extended wavelength ranges. On the one hand, the correct mechanical coupling was verified. Accordingly, the irradiance at the image sensor level differs by only 0.2 % from that at the radiometers. The determined inhomogeneity ΔE of the radiation source of approx. 2 % is within the maximum permissible inhomogeneity of the EMVA 1288 standard of 3 %. The correct calculation of the spectral irradiation sensitivity of the radiometers could be verified quantitatively by the measurement with a monochromator and the comparison with the spectrum of its Xe arc lamp. The correctness of the absolute measured values of the new radiometric measuring system was qualitatively confirmed by a comparison measurement of the VISNIR radiometer with a calibrated luxmeter. The irradiance of the VISNIR radiometer deviated from that of the luxmeter only by a maximum of 1 %, which is within the relative measurement uncertainty of the radiometer.

References

- [1] Erz M and Jähne B 2010 *Forum Bildverarbeitung* ed Puente León F and Heinzmann M (Regensburg: KIT Scientific Publishing) pp 155–166
- [2] European Machine Vision Association 2016 *EMVA Standard 1288 – Standard for Characterization of Image Sensors and Cameras (release 3.1)* www.emva.org
- [3] Gigahertz-Optik GmbH, <https://www.gigahertz-optik.de> Access on 13.11.2018
- [4] Gigahertz-Optik GmbH 2017 calibration certificate 1642353-05 (Türkenfeld)
- [5] Gigahertz-Optik GmbH 2017 calibration certificate 1740347-02 (Türkenfeld)